INP BASED LONG WAVELENGTH VCSEL

BACKGROUND

The invention pertains to laser light sources and particularly to vertical cavity surface emitting lasers. More particularly, the invention pertains to long wavelength surface emitting lasers.

A vertical cavity surface emitting laser (VCSEL) may include a first distributed Bragg reflector (DBR), also referred to as a mirror stack, formed on top of a substrate by semiconductor epitaxial growth techniques, an active region formed on top of the first mirror stack, and a second mirror stack formed on top of the active region. The VCSEL may be driven by a current forced through the active region, typically achieved by providing a first contact on the reverse side of the substrate and a second contact on top of the second mirror stack. The first contact may instead be on top of the first mirror stack in a coplanar arrangement.

VCSEL mirror stacks are generally formed of multiple pairs of layers often referred to as mirror pairs. The pairs of layers are formed of a material system generally consisting of two materials having different indices of refraction and being lattice matched to the semiconductor substrate. For example, a GaAs based VCSEL typically uses an AlAs/GaAs or $Al_xGa_{1-x}As/Al_yGa_{1-y}As$ material system wherein the different refractive index of

each layer of a pair is achieved by altering the aluminum content in the layers. The number of mirror pairs per stack may range from 20 to 50 to achieve a high percentage of reflectivity, depending on the difference between the refractive indices of the layers. The larger number of pairs increases the percentage of reflected light.

In many VCSELS, conventional material systems perform adequately. However, new products are being developed requiring VCSELs which emit light having longer wavelengths. VCSELs emitting light having a longer wavelength are of great interest in the optical telecommunications industry because of the low fiber dispersion at 1310 nanometers (nm) and the low fiber loss at 1550 nm. As an example, a long wavelength VCSEL may be obtained by using a VCSEL having an InAlGaAs/InAlAs active region. When an InAlGaAs/InAlAs active region is used, an InP/InGaAsP material system lattice-matched to the InP substrate may be used for the mirror stacks in order to achieve a lattice match. The lattice matching between the substrate and the layers need to be substantially close to ensure a true crystal film growth.

In the InP material based system, it is practically impossible to achieve a suitable monolithic DBR-based mirror structure because of the insignificant difference in the

refractive indices available in this lattice matched material system. As a result, many layers, or mirror pairs, are needed in order to achieve useful reflectivity. Useful reflectivity must generally be 99.8 percent or greater. Numerous attempts have been made to address this problem including a wafer bonding technique in which a DBR mirror is grown on a separate substrate and bonded to the active region. This technique has had only limited success and also the interface defect density in the wafer fusion procedure causes potential reliability problems. Other approaches to making satisfactory long wavelength VCSELs have been fraught with one problem or another. For instance, lattice matched InP based mirrors used for 1550 nm VCSELs have a host of problems in growth, processing, and optical performance. The low index contrast of lattice matched InGaAsP and InAlGaAs leads to the requirement of extremely thick (ten microns or thicker) DBRs of 45 or more mirror periods. The AlGaAsSb or AlGaPSb systems may be difficult to grow by MOCVD, and with good contrast, may still require at least 25 mirror pairs to achieve adequate reflectivity for VCSEL operation.

SUMMARY

The invention may be a vertical cavity surface emitting laser having a substrate, a first mirror situated on the

substrate, an active region situated on the first mirror, a second mirror situated on the active region. The first mirror may have several pairs of layers with an oxidized layer in one or more pairs of that mirror. The invention may incorporate group III-V material. The substrate may include InP.

This invention may solve the problem of having to grow many layers of low contrast semiconductor DBRs by including a fully oxidized layer for half of each DBR pair in the lower mirror. A fully oxidized InAlAs, InAlGaAs, AlAsSb, AlGaAsSb, AlGaPSb, or AlPSb layer converts to Al_xO_y, and when combined with InP, may have enough index contrast to reduce the required number of mirror pairs to less than six. Portions of the VCSEL structure may be effectively lattice matched. An electrical circuit may be completed by making an electrical contact on the second mirror and another contact that may be intracavity on the first mirror.

Similar to 850 nm AlGaAs oxidation, a ring of spoked trenches (more than four) may be etched into the semiconductor surface. The structure may then be subjected to an oxidizing environment until certain lower mirror layers are fully oxidized. Processing then may proceed similarly to standard intracavity contact processing, with the bottom contact electrical current flowing through the lower conductive

semiconductor layer between the etched trenches. Other options such as reversed growth design, oxidation, and wafer bonding are also possible means for utilizing fully oxidized InP based mirrors.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 illustrates a vertical cavity surface emitting laser;

Figure 2 reveals an illustrative example of a long wavelength InP material based VCSEL;

Figure 3 shows the VCSEL of Figure 2 with vertical trenches near the aperture for oxidizing certain layers in the lower mirror;

Figure 4 is a top view of the VCSEL of Figure 3 with the trenches;

Figure 5 shows the VCSEL of Figure 2 with vertical trenches near the outside perimeter of the device;

Figure 6 is a top view of the VCSEL of Figure 5 with the trenches;

Figure 7 reveals an illustrative example of the long wavelength VCSEL having an intracavity or coplanar configuration for the electrical contacts of the device;

Figure 8 shows the VCSEL of Figure 7 with vertical trenches near the aperture for oxidizing certain layers in the lower mirror;

Figure 9 is a top view of the VCSEL of Figure 7 with the trenches; and

Figure 10 reveals an illustrative example of a long wavelength VCSEL having a mesa-like island structure with a continuous isolation trench around the lower portion of the device that may be utilized in the oxidation of certain layers in the lower mirror.

DESCRIPTION

Figure 1 is a representation showing a perspective illustration of a structure for a vertical cavity surface emitting laser 11. A substrate 12 may be disposed on an electrical contact 14. A first mirror stack 16 and a bottom graded index region 18 may be progressively disposed, in layers, on substrate 12. A quantum well active region 20 may be formed and a top graded index region 22 may be disposed over active region 20. A top mirror stack 24 may be formed over the active region and a conductivity layer 26 may form an electrical contact. Current may flow from upper contact 26 to lower contact 14. This current may pass through active region 20.

Upward arrows in Figure 1 illustrate the passage of light through an aperture 30 in upper contact 26. The downward arrows illustrate the passage of current downward from upper contact 26 through upper mirror stack 24 and the active region 20. An ion implantation 40 may form an annular region of electrically isolated material. A central opening 42 of electrically conductive material may remain undamaged during the ion implantation process. As a result, current passing from upper contact 26 to lower contact 14 may be forced to flow through conductive opening 42 and thereby be selectively directed to pass through a preselected portion of active region 20.

Figure 2 shows an illustrative example of a long wavelength InP based VCSEL 10. A long wavelength may range from about 1200 nm through about 1800 nm. Figure 2 is not necessarily drawn to scale. There may be a lower (DBR) mirror 13 formed on an InP substrate 15. An active layer or cavity 17 may be formed on lower mirror 13. On active layer or cavity 17 may be an upper (DBR) mirror 19. Formed on upper mirror 19 may be a layer 21 of oxide. A trench 23 may be etched through the oxide layer 21 and upper mirror 19 down to but not into active layer 17. Since Figure 2 shows a side view of structure 10, trench 23 may appear to be two trenches. It is one trench because trench 23 and its associated structure 10 may be circular. Near the lower part of

upper mirror may be a layer 25 having a high content of aluminum. Layer 25 may be oxidized via the trench with a high temperature vapor, oxidizing agent or anything else that may cause the aluminum layer to oxidize at a controllable rate. Not the whole layer 25 is oxidized. It may be oxidized only to an extent to form an aperture 27 within the non-oxidized area for current control and confinement.

A mask (not shown) may be put on the central portion of structure 10 as shown by a dimension 29. Then an ion implantation 31 may be applied to create an electrical isolation of structure and a confinement of current within dimension 29 in structure 10. Implantation 31 may penetrate a top portion of top mirror 19 and an upper part of lower mirror 13 via the bottom of trench 23. The mask may then be removed. A layer 33 of nitride or the like may be formed on oxide 21 and trench 23. On layer 33 a layer 35 of oxide may be formed. Then a mask covering the area of about where implantation 31 was applied and the central portion of oxide layer 35 not masked may be removed leaving nitride layer 33 below it. With the same mask, the central portion of nitride layer 33 may be removed. That mask may be removed and replaced with a mask covering about the same area as the previous mask plus a portion on oxide layer 21 in the center of structure 10. Then a ring-like shape of the

unmasked area incorporating an exposed portion of oxide layer 21 may be removed. On everything at the top of the structure, a layer 37 of metal may be applied. The masking material including metal 37 on the masking may be removed leaving a ring of metal layer 37 on the top of upper mirror 19. This remaining layer 37 may be an electrical contact for VCSEL structure 10. A mask may be placed on the central portion (which may be circular) of oxide layer 21 and most of the metal ring layer 37. Another layer 39 of may be applied on oxide layer 35 plus an outside edge of metal layer 37 for connection to the latter. The mask may be removed exposing again the central portion of oxide layer 21 and metal contact layer 37. Contact layer 37 and metal layer 39 are connected to each other. The bottom of substrate 15 may have a metal layer 41 formed on it. Metal layer 41 may constitute the other electrical contact for VCSEL structure 10.

Top mirror 19 which is formed on active layer or cavity 17 may be composed of about 35 pairs of quarter-wavelength layers. The layers may consist of alternating materials. For instance, a pair of materials may be InGaAsP and InP, or AlGaAsSb and InP, or AlGaPSb and InP. Layer 43 may be a quarter-wavelength thick of InP material and layer 44 may be a quarter-wavelength thick of InAlGaAs or InGaAsP or AlGaAsSb or AlGaPSb material. On the

other hand, Layer 44 may be a quarter-wavelength thick of InP material and layer 43 may be a quarter-wavelength thick of InAlGaAs or InGaAsP or AlGaAsSb or AlGaPSb material. Or the order of the layers for each pair may be reversed. The wavelength may be an optical wavelength of the light that may be emitted from structure 10. Each pair of mirror 19 may include layers 43 and 44. These layers may be lattice matched to InP, and may or may not be fully N-doped. They may be partially doped for the intra-cavity type of device. Not all of the pairs are shown for upper mirror 19 in Figure 2. Another layer, a layer 25, in upper mirror 19 may be an easily oxidizable layer of a material relatively high in aluminum content such as InAlAs or other suitably oxidizable material. The extent of oxidation in layer 25 may extend to the inside periphery of a desired aperture for current confinement.

Active region/cavity 17 may be composed of InGaAs/InGaAsP; that is, it may have InAlGaAs strained quantum wells and InAlAs barriers, also of a strained composition. Active region/cavity 17 would not be doped but it may be unintentionally doped. Region 17 may have one to five quantum wells.

Lower mirror 13 may have a particular structure of about 6 pairs, or more or less, of layers 45 and 46. Figure 2 shows the mirror or stack 13 of layers to begin with layer 45 on substrate

15. However, the mirror or stack 13 of pairs of layers may instead begin with layer 46 on substrate 15. The materials are selected and conditioned so that there is a significant disparity of the indices of refraction between the two layers 45 and 46 for each pair. Layer 45 may be a non-oxidized InP or AlGaInAs material. Layer 46 may be an oxidized material of InAlAs, InAlGaAs, AlAsSb, AlGaAsSb, AlGaPSb, or AlPSb. When the material of layer 46 is fully oxidized, such material may convert to an Al_xO_y material. When this oxidized layer 46 is combined with layer 45, there may be enough contrast between the layers to result in a sufficiently reflective lower mirror 13 having less than 6 pairs of layers.

Layers 46 may be oxidized in several ways. They may be oxidized from the edge of structure 10 if it is cut or sawed from a wafer as a separate chip or die. Or, as illustrated in Figure 3, vertical trenches 47 may be made from the top down through oxidizable layers 46 in lower mirror 13. Trenches 47 may be individual trenches of limited length and do not surround the device in a complete circle as trench 23 does, although they may be placed completely around the structure. The aluminum content of InAlAs, for example, may be about 52 percent, so as to be lattice matched to InP. Structure 10 of Figure 3 may be put into and oxidizing environment such as a furnace with H_2O

steam. The environment in the furnace may range from 350 to 500 degrees Celsius. The structure may be subject to such environment for about 3 hours to fully oxidize layers 46 in lower mirror 13 via trenches 47. This oxidation should not affect the other layers since their resilience to this oxidation may be sufficiently significant to resist such oxidation. Figure 4 shows a top view of structure 10 having trenches 47. This figure may not necessarily be drawn to scale or have the same scale of Figure 3.

Figure 5 shows trenches 48 use to convey an oxidizing agent such as vapor at 300 to 500 degrees Celsius in a furnace to layers 46 of lower mirror 13. Trenches 48 may be situated at the periphery of structure 10. Figure 6 shows a top view of structure 10 having trenches 48. This figure may not necessarily be drawn to scale or have the same scale of Figure 5.

Figure 7 shows another illustrative structure 50 of the invention. Figure 7 is not necessarily drawn to scale. Structure 50 may have an intracavity or coplanar design relative to the electrical contacts of the VCSEL. There may be a lower (DBR) mirror 13 formed on an InP substrate 15. An intra-cavity contact layer 51 may be formed on lower mirror 13. An active layer or cavity 17 may be formed on layer 51. On active layer

or cavity 17 may be an upper (DBR) mirror 19. Formed on upper mirror 19 may be a layer 21 of oxide. A trench 23 may be etched through the oxide layer 21 and upper mirror 19 down to but not into active layer 17. Figure 7 shows a side view of structure 50 and trench 23 might seem to be two trenches in this view. But it is one trench because trench 23 and its associated structure 50 may be a circular one. Near the lower part of upper mirror may be a layer 25 having a high content of aluminum. Layer 25 may be oxidized via the trench with a high temperature vapor, oxidizing agent or anything else that may cause the aluminum layer to oxidize at a controllable rate. Not the whole layer 25 is oxidized. It may be oxidized around a perimeter to form an aperture 27 within the non-oxidized area for current confinement and optical index guiding.

A mask (not shown) may be put on the central and left portions of structure 50 from the left edge of structure 50 to a short distance before trench 23 on the right side. Then an ion implantation 31 may be applied to create an electrical isolation from items outside of the top contact on the right side of structure 50 in Figure 7. Implantation 31 may penetrate a top portion of top mirror 19 on both sides of that portion of trench 23 and an upper part of lower mirror 13 via the bottom of trench

23 in that portion of structure 50. The mask may then be removed.

A layer 33 of nitride or the like may be formed on oxide 21 and in trench 23. On layer 33 a layer 35 of oxide may be formed. Then a mask may be applied covering the top area except the central portion of oxide layer 35 just inside the inside perimeter of trench 23. The central portion of oxide layer 35 may be removed leaving nitride layer 33 below it. With the same mask, the central portion of nitride layer 33 may be likewise removed. That mask may be stripped and replaced with a mask covering about the same area as the previous mask plus a portion on oxide layer 21 in the center of structure 50. Then a ring-like shape of the unmasked area incorporating an exposed portion of oxide layer 21 may be removed. On the top of structure 50, a layer 37 of metal may be applied. The masking material including metal 37 on the masking may be removed leaving a ring of metal layer 37 on the top of upper mirror 19. This ring-like layer 37 may be an electrical contact for VCSEL structure 50. A mask may be placed on the central portion (which may be circular) of oxide layer 21 and most of the metal ring layer 37. Another layer 39 of may be applied on oxide layer 35 plus an outside edge of metal layer 37 for connection to the latter. The mask may be removed exposing again the central portion of

oxide layer 21 and metal contact layer 37. Contact layer 37 and metal layer 39 are connected to each other.

Another mask may be formed on the top of structure 50 except for a portion just to the left of trench 23 of Figure 7. The unmasked left portion 52 over layers 35, 33 and 21 may be etched down in one step. Next, in that portion or area 52, mirror 19 and active area 17 may be etched down to intra-cavity contact layer 51. Then mirror 19 and active area 17 may be etched in towards the center of structure 50 resulting in an undercut 53 under layers 21, 33 and 35. A layer of metal may be formed on the top of structure 50 resulting in an electrical contact 54 on a left area of intra-cavity contact layer 51 but not touching the edge of mirror 19 and active region or layer 17 because of undercut 53. Contacts 54 and 37 are the two VCSEL contacts of co-planar structure 50. The mask and metal on it are removed from the structure.

Top mirror 19 which is formed on active layer or cavity 17 may be composed of about 35 pairs of quarter-wavelength layers. The layers may consist of alternating materials. For instance, a pair of materials may be InGaAsP and InP, or AlGaAsSb and InP, or AlGaPSb and InP. Layer 43 may be a quarter-wavelength thick of InP material and layer 44 may be a quarter-wavelength thick of InGaAsP or AlGaAsSb or AlGaPSb material. Each pair of mirror

19 may include layers 43 and 44. The order of layers 43 and 44 may be reversed. These layers may be lattice matched to InP and may or may not be fully N-doped. They may be partially doped for the intra-cavity type of device. Not all of the pairs are shown for upper mirror 19 in Figure 7. One of the layers, that is layer 25, in upper mirror 19 may be an easily oxidizable layer of a material relatively high in aluminum content such as InAlAs or other suitably oxidizable material. The extent of oxidation in layer 25 may extend to the inside periphery of a desired aperture for current confinement.

Active region/cavity 17 may be composed of InAlGaAs/InAlAs; that is, it may have InAlGaAs strained quantum wells and InAlAs barriers, also of a strained composition. Active region/cavity 17 would not be doped but it may be unintentionally doped. Region 17 may have one to five quantum wells.

Lower mirror 13 may have a particular structure of only about 6 pairs, or less, of layers 45 and 46. There may be design reasons to have one or a few more pairs. The materials are selected and conditioned so that there is a significant disparity of the indices of refraction between two layers 45 and 46 for each pair. Layer 45 may be a non-oxidized InP or AlGaInAs material. Layer 46 may be an oxidized material of InAlAs, InAlGaAs, AlAsSb, AlGaAsSb, AlGaPSb, or AlPSb. When the

material of layer 46 is fully oxidized, such material may convert to an Al_xO_y material. When this oxidized layer 46 is combined with layer 45, there may be enough contrast between the layers to result in a sufficiently reflective lower mirror 13 having less than 6 pairs of layers. The order of layers 45 and 46 may be reversed.

Layers 46 may be oxidized in several ways. They may be oxidized from the edge of structure 50 if it is cut or sawed from a wafer as a separate chip or die. Or, as illustrated in Figure 8, vertical trenches 55 may be made from the top down through oxidizable layers 46 in lower mirror 13. Trenches 55 may be individual trenches of limited length and do not surround the device in a complete circle as trench 23 does, although they may be placed completely around the structure. The aluminum content of InAlAs for example may be about 52 percent. Structure 50 of Figure 8 may be put into and oxidizing environment such as a furnace with H_2O steam. The environment in the furnace may range from 300 to 500 degrees Celsius. The structure may be subject to such environment until layers 46 are fully oxidized in lower mirror 13 via trenches 55. This oxidation should not affect the other layers since their resilience to this oxidation may be sufficiently significant to resist or slow the rate of steam oxidation. Figure 9 shows a

top view of structure 50 having trenches 55. This figure may not necessarily be drawn to scale or have the same scale of Figure 8. Trenches 55 may be placed in a perimeter outside of that of trench 23 in a similar manner as trenches 48 in Figure 6.

Figure 10 shows a structure 60 having a mesa-like island 61. The oxidizable layers 46 of lower mirror 13 may be oxidized via a ring-like trench 62 of structure 60 which may also be used for isolation purposes for structure 60 similar to those of trench 23 in structure 10 of Figure 2. An alternative way for oxidizing layers 46 may be done via trenches similar to trenches 47 of structure 10 in Figures 3 and 4, or trenches 48 in Figures 5 and 6, as discussed above.

Although the invention has been described with respect to at least one illustrative embodiment, many variations and modifications will become apparent to those skilled in the art upon reading the present specification. It is therefore the intention that the appended claims be interpreted as broadly as possible in view of the prior art to include all such variations and modifications.